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Neurogenomics: An opportunity to integrate neuroscience, genomics and bioinformatics research in Africa

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ABSTRACT

Modern genomic approaches have made enormous contributions to improving our understanding of the function, development and evolution of the nervous system, and the diversity within and between species. However, most of these research advances have been recorded in countries with advanced scientific resources and funding support systems. On the contrary, little is known about, for example, the possible interplay between different genes, non-coding elements and environmental factors in modulating neurological diseases among populations in low-income countries, including many African countries. The unique ancestry of African populations suggests that improved inclusion of these populations in neuroscience-related genomic studies would significantly help to identify novel factors that might shape the future of neuroscience research and neurological healthcare. This perspective is strongly supported by the recent identification that diseased individuals and their kindred from specific sub-Saharan African populations lack common neurological disease-associated genetic mutations. This indicates that there may be population-specific causes of neurological diseases, necessitating further investigations into the contribution of additional, presently-unknown genomic factors. Here, we discuss how the development of neurogenomics research in Africa would help to elucidate disease-related genomic variants, and also provide a good basis to develop more effective therapies. Furthermore, neurogenomics would harness African scientists' expertise in neuroscience, genomics and bioinformatics to extend our understanding of the neural basis of behaviour, development and evolution.

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1. Introduction

Human populations globally show genetic and genomic diversity. Improved understanding of this diversity can provide information that would shape the future of basic, applied and translational medicine (Gurdasani et al., 2015). Until recently, not much was known about genomic diversity among the different African populations. However, recent developments in research funding, training and infrastructure are making important contributions to building genomics research capacity on this continent (H3Africa Consortium et al., 2014). This means that major biomedical research questions relevant to the African population can be addressed by research scientists working in Africa. A significant example is the recent sequencing and assembly of the tsetse fly genome which is aiding in-depth studies into Human African trypanosomiasis disease biology (International Glossina Genome Initiative, 2014). Additionally, whole genome sequencing and bioinformatic analyses of patients' genomes during the recent Ebola virus disease outbreak provided vital information on disease epidemiology and future directions (Gire et al., 2014). The African Genome Variation Project also recently characterised genomic variations among certain key African ethnic groups (Gurdasani et al., 2015). These developments are a few examples demonstrating that genomics hold a lot of promise for biomedical research and medical care in Africa, particularly in providing insights into individual and population variations in disease susceptibility and resistance, as well as differential drug responses. The decreasing costs of high-throughput sequencing technologies also offer an opportunity to African laboratories in acquiring such technologies to advance their research activities (Karikari, in press).

While *genetics* refers to the study of single genes and their associated biological effects, *genomics* is usually concerned about studying the totality of genes and non-coding elements in an individual's genome (i.e., the complete collection of genes and genetic material in the organism), in order to identify how these components function individually or collectively. Due to the wide coverage of sequencing technologies, it has been possible to extensively characterise genetic variants in populations studied to date, as well as gain in-depth insights into disease mechanisms and the development of potential therapies. Genomic diversity may lead to variations in the neural basis of development (neurodevelopment), behaviour (neurobehaviour), evolution (neuroevolution) and drug response (neuropharmacology); the study of these areas is referred to as neurogenomics (Boguski and Jones, 2004; Chandrasekaran et al., 2011; Deriziotis and Fisher, 2013; Tsuji, 2013). While genomics research is developing in Africa, there is limited application of these advances in neuroscience. Here, we discuss that the further development of neurogenomics in Africa would help to obtain further genomic-scale insights into neurological diseases, through the combined efforts of expertise in neurobiology, genome science and bioinformatics.

2. Neuroscience research in Africa

Comprehensive acounts of the state of neuroscience in Africa have been previously provided (Karikari et al., in press; Yusuf et al., 2014). Regardless of the many challenges in research funding, expert training and research infrastructure, significant progress has been recorded in developing neuroscience research capacity in Africa (Karikari et al., in press). The area appears to be dominated by neuropharmacognosy research; many studies investigate the disease-modifying benefits of administering herbal extracts and other natural products to experimental organisms. African researchers are in a unique position of having access to ecosystems of high biodiversity in combination with knowledge of traditional medicine, the scientific testing of which may lead to the discovery of new bioactive compounds. Complementing neuropharmacognosy with neurogenomics can help to extend the findings of current research, by focusing on molecular disease mechanisms, characterising in-depth the genomic effects of the compounds, and using bioinformatics methods to predict drug efficacy, in order to potentially match different compounds with diseases that they would work on. These approaches could also be used to characterise the effects of each drug in different genetic backgrounds, aiding research into precision medicine and improving patient treatment. If appropriately employed, neurogenomics would help to strengthen molecular pharmacognosy, drug development and the growing herbal medical industry in Africa (Street and Prinsloo, 2012; van Andel et al., 2012).

Invertebrate model organisms such as *Drosophila melanogaster* have been introduced to African neuroscientists as powerful-yet-low-cost alternatives to the mammalian models often used (Karikari et al., in press; Muindi and Keller, 2015; Yusuf et al., 2014). The genomically simple organism *D. melanogaster* has been used extensively in neuroscience research worldwide, especially in investigating the neural basis of development, behaviour, evolution, and disease (Allen et al., 1998; Carhan et al., 2003; Eddison et al., 2011; Karikari et al., 2015a; Reeve et al., 2007). Their simple genomes; short life spans and reproduction cycles; and powerful genetic, biochemical and structural tools are some of the advantages that make invertebrate systems useful for genetics-related research (Moffat, 2008). The inexpensive maintenance of inverterbrate organisms in experimental conditions also makes them particularly beneficial in areas of low research funding (Moffat, 2008).

3. Clinical neuroscience in Africa

Expertise in clinical neuroscience disciplines (such as neurosurgery, neuropsychiatry and clinical neurology) is essential to collect neurogenomics data from human subjects, analyse and make inferences from these data and also to integrate genomic approaches into clinical diagnosis and treatment processes in order to advance the wellbeing of patients and improve efficiency in healthcare delivery. To develop neurogenomics research and application in African health facilities, interdisciplinary collaborations in this area need to be encouraged, for example through meetings and training courses. Further to this, more clinicians in neuroscience-related specialties should be trained in the clinical applications of genome science, to enable them incorporate the new knowledge into clinical procedures to improve the timeliness and accuracy of disease diagnosis and treatment. In areas where clinical neuroscientists are lacking, general practitioners with the appropriate training can help to integrate neurogenomics in clinical settings.

While neurology started in Africa (Egyptian physicians were the first to describe the brain, and also recognised major brain-related diseases (Martín-Araguz et al., 2002)) and neurology practice can be traced to native African physicians many millenia ago (for example, native Yoruba physicians in Nigeria practised neurology in a traditional way

(Osuntokun, 1975)), the continent currently lags behind in terms of human resources and facillities for neurology practice (Owolabi et al., 2007). Generally, clinical neuroscientists are lacking across Africa, with low neurologist-to-population ratios recorded in many countries. While the best-ranked countries have one neurologist per 162,885 residents, ranking close to the United States (US) and European countries that have a neurologist for between every 40,000-125,000 residents, in contrast, the least resourced countries have no resident neurologist (Owolabi et al., 2007). Ghana, for instance, has only a couple of neurologists serving a population of about 26 million (Drislane et al., 2014a). Compared with leading countries such as the US where the neurologist:population ratio is about 1:29,200, a neurologist in the African country with the highest neurology workforce serves about six times more people (Owolabi et al., 2007). The neurologist-to-population ratios all over Africa fall behind the one neurologist to 100,000 persons ratio recommended by the World Health Organization (Bower and Zenebe, 2005). The dearth of neurologists in Africa has negative implications for clinical neuroscience practice, teaching and research. Neurology research is poor on the continent; a survey identified that the number of articles with authors/co-authors affiliated to African institutions and published in leading neurology journals were very low compared to the total number of articles (for example, only seven out of over 1500 articles published in four leading neurology journals in 2005 had authors affiliated to African institutions) (Owolabi et al., 2007). Since most neurologists do practise in cities, the majority of Africans who reside in rural areas have difficulty accessing neurological care (Bower and Zenebe, 2005). Additionally, not much information is documented about neurology training programmes in Africa, although there is a general lack of residency programmes (Bergen and Good, 2006). Nonetheless, the situation seems to be improving with the establishment of pro-rural medical residency programmes (Drislane et al., 2014b). Also, the International Parkinson and Movement Disorder Society and the World Federation of Neurology have been organising training courses for non-neurology specialist clinicians in West Africa, aimed at improving their knowledge in neurology to aid clinical practice (Cilia, 2013). More programmes of this nature would be essential to improve the capacity of clinicians for neurogenomics use in Africa.

4. Neurogenomics: an opportunity to develop and apply genomic tools to advance neuroscience in Africa

The genome sequence differences recorded among African populations and also between Africans and other populations suggest a need for additional research aimed at identifying how these variations might lead to neurogenomic differences. In this section, we discuss how neurogenomics would support biomedical research and medical care in neurology, neurobehaviour and neurodevelopment, and promote pan-African collaborative research in neuroscience, genomics, and bioinformatics.

4.1. Studying genomic basis of neurological diseases

Most of the studies on neurological diseases in Africa have been focused on disease epidemiology, conducted among limited populations in a few countries (Lekoubou et al., 2014). Only a few studies investigating the molecular and genetic aspects of these diseases among Africans exist (Blanckenberg et al., 2013). Significantly, most studies conducted among sub-Saharan Africans found that common disease-associated genetic mutations were missing in patients' genomes (Blanckenberg et al., 2013; Cilia et al., 2012; Logue et al., 2011; Quansah and Karikari, in press; Yonova-Doing et al., 2012). On the contrary, some of these mutations have been identified in diseased individuals in North Africa (Lesage et al., 2009), suggesting that the genetic causes of these diseases may be population-specific. Notably, the *LRRK2* G2019S mutation in Parkinson's disease is believed to have originated from common founder mutations from Middle East and North Africa (Zabetian et al., 2006). The absence of this and other disease-associated mutations among sub-Saharan African study subjects suggests that common disease mutations are unlikely to be the causes of some neurological diseases within this population; this may have serious implications for disease treatment. For example, drugs that work for diseased individuals within one population may not work for the other. This necessitates further investigation to identify the role of additional, presently-unknown genetic factors responsible for neurological diseases in Africa (Quansah and Karikari, in press; Yonova-Doing et al., 2012). Better understanding of the genetic causes of these diseases among and between African populations would be a key step in advancing molecular mechanisms that regulate the diseases, which would also lead to the development of better-targeted therapies. Furthermore, the above findings support the idea that there is an urgent need for long-term planning and support to prepare the continent for the estimated future increases in the burden of neurological diseases, as well as the economic, health and social burdens usually associated with these diseases (Dua et al., 2006; Lekoubou et al., 2014).

4.2. Genome-level studies into neurobehaviour

Within the animal kingdom, incredible diversity in behaviour exists. The decisions of many animals, including humans, who live in complex social environments are often dependent on their interactions with other individuals (Harris and Hofmann, 2014). Social and reproductive behaviours vary among animal species; interestingly, genomic variants have been found to influence these behavioural differences (Harris and Hofmann, 2014). The application of genomic techniques has enabled scientists to obtain insights into the molecular and neural basis of organismal behaviour and decision-making, as well as how these features have evolved over time (Harris and Hofmann, 2014; O'Connell and Hofmann, 2011). It is believed that specific genes or gene products concomitantly regulate these behaviours, although the evidence base is weak as to whether these behaviours are evolutionarily conserved or are affected by environmental factors, and why it would be so (Harris and Hofmann, 2014; Oers and Mueller, 2010). Further studies may lead to the identification of novel genes or other genome regions modulating behavioural traits in different social contexts, and how gene expression levels, gene networks, gene–environment interactions, gene products or pleiotropic elements may affect personality phenotypes in different ecological settings (Oers and Mueller, 2010). The African continent is a promising area for this type of research, due to its very high biodiversity, as well as very high social diversity and range of subpopulations. Different high throughput techniques can be used here, including genome sequencing to characterise population-based genetic variants, possibly followed by RNA sequencing and epigenetic studies. Already, various genomic factors have been shown to be playing roles in behavioural conditions such as alcoholism, and nicotine and cocaine addiction (Caron et al., 2005; Heberlein et al., 2009; Mulligan et al., 2011). Since various model organisms are used in this area of research, platforms such as ENCODE, modENCODE and InterMOD that allow the integration of genomic data and tools to support cross-species research may be useful here, and provide publicly-available data to use as a starting point for research (Gerstein et al., 2010; Roy et al., 2010; Sullivan et al., 2013; The ENCODE Project Consortium, 2004).

4.3. Genomic studies into neurodevelopment

During organismal development, specific changes in gene expression are required for differentiation and body plan development (Aleksic et al., 2013; Allen et al., 1998; Easter et al., 1996; Kimmel et al., 1995; Reeve et al., 2007; Shen et al., 2013; Singh et al., 2014). Tissue-specific gene expression is usually conserved across species; disruption to the amount or timing of expression could affect multiple molecular pathways leading to neurodevelopmental impairments (Nüsslein-Volhard and Wieschaus, 1980; Zhu et al., 2014). Neurodevelopmental disorders can include developmental brain

dysfunctions manifesting as problems in neuropsychiatric, learning, language, speech, motor, and non-verbal communication functions (Zhu et al., 2014). Although genomic factors have been shown to be involved in the biology of neurodevelopmental disorders (Deriziotis and Fisher, 2013; Tsuji, 2013), the evidence from African populations is scanty. Given that African populations have a unique lineage, and are often distinct from the non-African populations on whom most available research has been conducted, it might be interesting to ascertain whether future research focused on or involving Africans would provide novel findings. This would improve future genetic diagnosis in the area of neurodevelopmental diseases for the African population. This is also relevant for drug development, the testing of drug safety, and for the emerging field of precision medicine, which requires the right background populations to be studied in detail. While neurodevelopmental disorders are beginning to attract research attention in Africa, culture still has a huge effect on the perceptions and care for people suffering from such disorders (Bakare and Munir, 2011; Ndung'u and Kinyua, 2009). Aside from increasing research efforts, public-focused outreach initiatives discussing neurodevelopmental disorders and neuroscience advances will be needed (Karikari et al., 2015b).

4.4. Development and application of neurogenomic tools in clinical diagnosis and treatment

Relying on disease symptoms, instead of molecular markers, for diagnosing and treating neurological and neuropsychiatric disorders poses a challenge to clinicians, including the risk of false positives, due to overlapping clinical symptoms often presented by patients (Rickards, 2005). This challenge is much more acute in Africa where many healthcare institutions and professionals are unequipped with molecular and genetic diagnostic platforms. Importantly, the discovery that some biomarkers (such as disease-causing genetic mutations) are absent from specific African populations also indicates that common diagnostic and treatment options may not necessarily work for them. It is therefore essential that further research is conducted to identify novel, clinically-relevant disease biomarkers that will improve the development and application of genomic tools in the neurology clinic in Africa. Altogether, increasing neurogenomics research and use in Africa would help to improve specificity and timeliness of clinical diagnosis and treatment of neurological diseases.

4.5. Pan-African collaborative research and training in neuroscience, genomics and bioinformatics

Neurogenomics requires the involvement of a broad scientific community (Insel et al., 2004). It provides collaborative opportunities for scientists with expertise in areas such as neuroscience, genomics and bioinformatics. While neuroscientists would bring their skills and knowledge in experimental neurobiology, genomics researchers would complement these with expertise in the design and implementation of high-throughput sequencing technology-based experiments. Also, since modern sequencing approaches require familiarisation with informatics tools and techniques needed to accession samples, analyse data and report findings (Sharma et al., 2013), bioinformaticians would also be needed in neurogenomics research projects. These fields are either established or developing areas in Africa, with considerable scientific capacity available (Bishop et al., 2015; H3Africa Consortium et al., 2014; Karikari, in press; Yusuf et al., 2014). The increasing infrastructural and funding investments in genomics-related research in Africa provides opportunities to identify scientists with interests in these areas, and collaborate to answer questions of relevance to neurogenomics. The establishment of genomic sample repositories in key African institutions, such as those established by the H3Africa Consortium, will also provide great benefit in this area (Adoga et al., 2014; H3Africa Consortium et al., 2014). Significant examples of these benefits will include improved cost- and time-effectiveness in accessing archived samples for neurogenomics experiments (H3Africa Consortium et al., 2014). Importantly, the established guidelines on genomic sample collection, data sharing and research collaboration in Africa will also be useful in this regard, ensuring fairness and transparency, as well as scientific replicability (de Vries et al., 2015). Collaborative research efforts in neurogenomics (whether between scientists in the same institution, country or even in multiple countries) would also present many opportunities to scientific knowledge advancement in Africa, such as student training and clinical care. For example, improved understanding of the genomic and molecular underpinnings of memory, attention and stress can contribute to improving learning and education (Edelenbosch et al., 2013).

Additionally, improved neurogenomics research in Africa would help to develop student training in this area. This is because developing research facilities often leads to increased student access to equipment and expert training. Teaching neuroscience, like many other scientific disciplines, is a challenging endeavour in Africa due to the lack of experimental resources (Karikari, 2015a; Karikari et al., 2015b). To overcome this challenge, scientists in bench research-intensive disciplines have been encouraged to partner with their colleagues in the computational sciences, to jointly develop alternative teaching approaches (Karikari, 2015b). Neurogenomics would support student training through, for example, the involvement of students in the application of web-based bioinformatics tools for predicting and analysing specific conditions. The low-cost nature of bioinformatics combined with the availability of large quantities of free, publicly-available genomics data, presents many opportunities in this area (Karikari, in press).

5. Advantages and challenges of neurogenomics research and use in Africa

While Africa has some unique features that would enable neurogenomics research and application, specific challenges need to be addresed to enable this transformation. In this section, we highlight these enabling factors as well as the weaknesses that should be tackled. A summary of this discussion is provided in Table 1.

5.1. Advantages

The relatively less-studied genetic diversity, unique gene-environment interactions and local traditional medicine practice are some of the potential advantages of neurogenomics in Africa. Moreover, the growing research interest in genomics as well as the establishment of research funding, data and sample repository systems provide essential platforms and foundations for this area of research.

5.1.1. High genetic diversity

African populations have higher levels of genetic and phenotypic diversity and extensive population substructure compared to non-African populations (Campbell and Tishkoff, 2008; Gomez et al., 2014). It is believed that modern humans originated in Africa many years ago and some subsequently migrated to other parts of the world; this is often referred to as the *out of Africa migration* (Ashraf and Galor, 2011; Gomez et al., 2014). This makes the genetic study of African populations interesting, since it might provide further clues into the genetic basis of evolution and adaptation. Furthermore, the genetic diversity and adaptation among Africans have evolved over time in response to diverse conditions such as diseases, climates and diets (Campbell and Tishkoff, 2008). Notable examples of genetic-dependent disease susceptibility and resistance among Africans have been previously shown in tuberculosis and malaria, respectively (Thye et al., 2012; Timmann et al., 2012). As indicated above, this population-based genetic difference also appears to regulate predisposition to some neurological diseases. The rich genetic diversity among and between African

Table 1
Summary of advantages and challenges of neurogenomics in Africa.

Advantages	Challenges
High genetic diversity and varying gene-environment interactions among and between African populations serve as valuable resources for studying genomic regulation of exposure to, and protection from, specific diseases.	Lack of a high number of appropriately-trained scientists and clinicians to lead neurogenomic activities is challenging to the development of the field.
The practice and knowledge of traditional medicine provides an opportunity to open up new research areas in order to search for bioactive compounds.	The low availability of research and clinical resources for genomics use is a limiting factor for research.
Potential contribution of traditional medicine to drug discovery and development as well as drug safety and efficacy evaluation.	Potential problems in the ethical, legal and social implications of genomic data collection and use might affect participant vulnerability and the willingness of populations to enrol in studies.
Neurogenomics would help to extend existing neuropharmacognosy research in Africa, by helping to provide further insights into the molecular mechanisms of disease and disease-modifying benefits of bioactive compounds.	Inadequate funding of genomics research by African governments leaves the sustainable development of the field in a questionable state.
Established genomic data sharing frameworks would ensure fairness in data collection, sharing and use.	Neurological problems associated with non-neurological diseases might be challenging to study, especially among laboratories with limited resources.
Recent genomic research funding and capacity-building programmes by specific international agencies are helping to establish good foundations and platforms for this area of research in Africa.	
Interest in genomic research is growing among African scientists; this is helping to build a large number of scientists with expertise in genomic technologies as well as institutions with the required facilities.	
Decreasing costs of sequencing technologies also provide an advantage to laboratories with limited funding to be able to afford such resources.	

populations provides an advantage to study population-dependence of disease susceptibility, resistance and propagation, as well as the evolutionary history behind these characteristics. The long histories shared by African populations provide prospects for improving the accuracy of ancestral haplotype construction (Peprah et al., 2015). Broadening genomic studies to include Africa's diverse ethnic groups would enhance understanding into differential neurological disease risks, and the application of this knowledge to enhance drug development and disease treatment.

5.1.2. Traditional medicine

Traditional medicine used to be the most dominant healthcare delivery system in the pre-colonial era in Africa (Abdullahi, 2011). This means that traditional treatment of disease, including neurological conditions, has been around for several centuries (Osuntokun, 1975). Currently, traditional medicine remains as a frequently-used and trusted source of care for a good proportion of the African population, especially in rural areas where conventional medical facilities are lacking (Abdullahi, 2011). While the lack of standard procedures and regulatory frameworks sometimes make the reliability of traditional medicine questionable, efforts have been made recently to streamline and regulate this system in several African countries, as well as integrate it into the orthodox healthcare delivery system. These efforts include the establishment of degree programmes in herbal medicine and the integration of graduates from these programmes into national health delivery systems to partner with orthodox physicians (Adusi-Poku et al., 2009; Ministry of Health, Republic of Ghana, 2007). African traditional healers usually classify various natural products according to product potency and diseases on which they act (Mahomoodally, 2013). However, most of this knowledge remains as undocumented indigenous knowledge. While reports on the effectivenesss of such products are available, the fact that they have not been studied in detail, especially in terms of their modes of action necessitates further studies (Mahomoodally, 2013). For instance, the application of genomic techniques would support bioactive compound discovery from plant products, as well as drug safety and effectiveness evaluation. This approach might lead to the identification and development of new and more effective natural product-based therapeutic agents. Moreover, the increasing drug resistance problem and the shortage of drug candidates in the discovery pipeline suggest that partnering with traditional medical practitioners who might be aware of potential drug candidates over the years may prove to be a useful venture.

5.1.3. Growing research interest in genomics

African researchers have joined genomics research activities with considerable interest and effort. Thanks to funding, infrastructure and training support from organisations such as the National Institute of Health and the Wellcome Trust, more African scientists are gearing up for genomics applications in biomedical research and clinical care (Adoga et al., 2014; H3Africa Consortium et al., 2014; Karikari, in press). Important examples here include the establishment of the Human Health and Heredity in Africa (H3Africa) programme which is aimed at supporting health-related genomics research in Africa, and the H3ABioNet which is helping to build expertise and collaboration in bioinformatics and genomics-related research in the continent. Further details about these programmes have been given elsewhere (Adoga et al., 2014; Bishop et al., 2015; H3Africa Consortium et al., 2014; Karikari, in press). Such capacity-building initiatives provide good platforms for scientists to collaborate and share resources to advance genomics research in Africa.

5.2. Challenges

Potential impediments include the low availability of expertise and resources in some countries for both experimental and clinical use of neurogenomics, as well as challenges in data sharing, pan-African collaborative research and the burden of diseases with neurological complications.

5.2.1. Lack of experimental and clinical resources and expertise

Genomics research is relatively new to most research and clinical institutions in Africa. For this reason, many of such institutions lack appropriately-trained scientists and the needed experimental resources (Karikari, in press; Mohamed, 2015). Currently, only a few leading institutions in Africa can be considered adequately-resourced for genomics applications (Bishop et al., 2015; Fatumo et al., 2014; H3Africa Consortium et al., 2014; Karikari, in press). This has negative consequences on student training, research capacity building, as well as research and healthcare delivery outcomes (H3Africa Consortium et al., 2014; Karikari, in press; Mohamed, 2015).

5.2.2. Ethical collection, sharing and re-use of neurogenomic data

As a new field to Africa, the ethical, legal and social implications of neurogenomics data collection and use have not been well-studied and documented, and might therefore pose a challenge to the advancement of the field. While African genomic data policy frameworks have been established, ethical considerations in the collection, sharing and re-use of genomic data remains a challenge (de Vries et al., 2015). Of particular concern is the use of samples and data that can identify

communities or individuals from whom the information was gathered (de Vries et al., 2014). Another issue is the ethical approval for genomic data usage (both primary and secondary use), especially among people of low educational levels and limited access to healthcare who might not adequately appreciate the need for their consent before being enrolled in genomic studies and might also interpret their inclusion in such studies as a favour (Wright et al., 2014). The under-resourced nature of many ethical review committees also often makes it difficult for them to appropriately regulate genomics research on the continent (Wright et al., 2014). Efforts should therefore be made to address participant vulnerability and other ethical issues in genomics research in Africa.

5.2.3. Lack of intra-continental collaborative research and research funding

Another potential challenge is the current lack of intra-continental collaborative research efforts in genomics, particularly in studying the genomic aspects of neuroscience (Karikari, in press; Karikari et al., in press). African scientists collaborate more often with their colleagues working out of Africa, compared to scientists affiliated to African institutions (Karikari, in press; The World Bank, 2014). This might be due to the often better-resourced nature of research groups in the developed world (both in terms of funding and laboratory resources), which possibly serve as natural attractants to their colleagues in developing countries. However, to be able to jointly identify and conduct research into Africa-focused challenges, more scientists working on the continent will need to combine their efforts and expertise (Karikari, in press; Karikari et al., in press). Furthermore, to promote intra-continental research and ensure that research directions are better aligned with the continent's developmental priorities, improved research funding especially from African governments and other local agencies will be required (Karikari, in press; Karikari et al., in press).

5.2.4. Heavy burden of diseases with associated neurological problems

Diseases such as malaria, Human Immunodeficiency Virus/Acquired Immune Deficiency Syndrome (HIV/AIDS), tuberculosis, and the neglected tropical diseases account for a high percentage of the disease and healthcare burden in Africa (Human Development Network — The World Bank and Institute for Health Metrics and Evaluation — University of Washington, 2013). Neurological problems are often associated with these diseases (Bangirana et al., 2011; Cherian and Thomas, 2011; Mireku et al., 2015; Robertson et al., 2010). This situation presents both a challenge and an opportunity to extend neurogenomics applications in Africa. While the complicated nature of investigating multiple diseases (for example, infectious diseases and their associated neurological problems) might prove challenging to scientists with inadequately-resourced laboratories, it would also provide an opportunity to explore how specific diseases (especially those prevalent in Africa) can affect neurological functions.

6. Introducing neurogenomics training in Africa

To help build capacity for neurogenomics in Africa, a few organisations have taken leading roles in offering training programmes for resident scientists. The H3ABioNet nodes (centres of excellence) across the continent regularly organise training programmes in genomics techniques and data analysis to interested scientists (Karikari, in press). Scientific societies such as the African Society for Bioinformatics and Computational Biology and the African Society for Human Genetics also provide capacity-development support in this area. To further extend this support system, non-profit organisations such as Teaching and Research in Natural Sciences for Development in Africa (TReND in Africa; http://trendinafrica.org) also organise training programmes in neuroscience and genomics data analysis for African scientists. These include annual neuroscience summer courses during which participants selected from across Africa are trained in how to use powerful-yet-cost-effective model organisms, tools and techniques for genetic and genomic studies (Baden et al., 2015; Karikari et al., in press; Yusuf et al., 2014). Additionally, TReND in Africa organises courses in next generation sequencing data analysis, to train African scientists in how to analyse and interpret genomic data. This course, which has been held at the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya, is to expand to other countries including Nigeria and Ghana in the near future. To help overcome the lack of experimental facilities and the high-cost involved in purchasing new ones, TReND in Africa also trains African scientists in how to build their own laboratory equipment through the use of open source resources (Baden et al., 2015; Karikari et al., in press).

7. Conclusion

Neurogenomics is an emerging field with enormous potential to advance neuroscience-related biomedical research and healthcare in Africa. However, studies exploring neurogenomic aspects of disease incidences, risk and propagation among Africans are lacking. The discovery that some African populations lack common disease-associated genetic mutations highlights the need and urgency for further studies. Gaining insight into the genomic causes of neuronal diseases in Africa would help to improve the timeliness and accuracy of clinical diagnosis and treatment. The use of existing genomics research facilities, as well as the establishment of new facilities dedicated to neurogenomics research would significantly benefit the continent. Importantly, substantial and sustainable financial investments towards training scientists and clinicians will be needed for Africa to fully benefit from this important research area.

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